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By

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MAIN AND CONTROL CIRCUITS OF
LONDON PASSENGER TRANSPORT 1938
TUBE ROLLING STOCK

LONDON

VIRTUE & COMPANY LIMITED

19-21 THAVIES INN, HOLBORN CIRCUS, E.C. 1

Printed in Great Britain by T. and A. Constable Ltd.
at the University Press, Edinburgh.

SUPPLEMENT TO ELECTRIC TRAINS

London Passenger Transport Board 1938 Tube Stock

In connection with the extension of Tube railways within the Boards area, additional trains have had to be constructed. The cars, which are built by Metropolitan-Cammell Carriage & Wagon Co. Ltd., and Birmingham Railway Carriage & Wagon Co. Ltd., are designed so that trains of 3, 4, 6, and 7 cars may be run, assembled as shown in Fig. 1.

The motor-cars are equipped with electro-pneumatic control apparatus, manufactured by British Thomson-Houston Co. Ltd.

Each motor-car is equipped with two Type LT100 motors of 168 horse-power, supplied by General Electric Co. Ltd., and Crompton Parkinson Ltd.

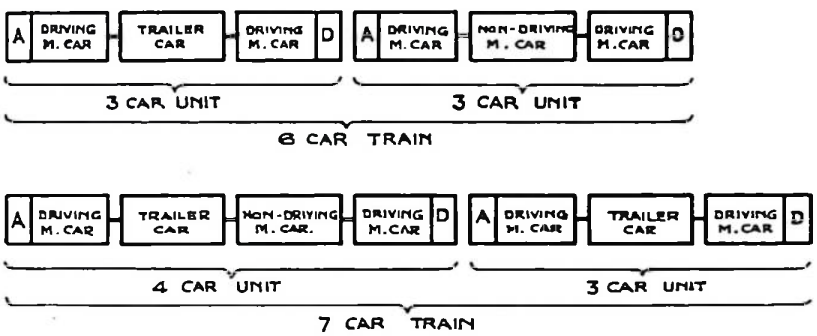


FIG. 1.—DIAGRAM OF TRAIN FORMATION.

A motor is fitted on each bogie, the bogie centre-bearing being off-set to bring some 66 per cent. of the total weight on the driving axle.

The control equipment is carried under the car underframes, with other auxiliary machinery and apparatus.

The motor-cars are of two types, one arranged with driving cab and the other without a driving cab, some 644 cars being of the former type and 161 being of the latter type.

In addition there are 261 trailer-cars without motors.

With a standard 7-car train composed of five motor-cars and two trailers, an acceleration of 1·7 miles per hour per second can be obtained, the maximum free-running speed being about 40 miles per hour with full-field excitation and about 48 miles per hour with 70 per cent. excitation.

The stock is provided with automatic couplers at points where trains are split for slack-hour working, the couplers being of the " wedgelock " type supplied by G. D. Peters & Co. Ltd. At other points of the train semi-permanent couplings are provided.

All cars are fitted with Westinghouse electro-pneumatic brake equipment, specially designed to secure a high rate of deceleration.

The new trains are equipped with air-operated doors, emergency lighting, telephones, etc., as is usual on London Transport Tube Stock, and various improvements have been made in lighting arrangements, ventilation, noise reduction and springing.

Main and Control Circuits.

The symbols used in the main and control circuit diagrams are illustrated and described below :

Positive Line-breaker magnet-valve coil.

Positive Line-breaker interlock closed when positive line-breaker is *closed*.

Positive Line-breaker interlock closed when positive line-breaker is *open*.

Negative Line-breaker magnet-valve coil.

Negative Line-breaker interlock closed when negative line-breaker is *closed*.

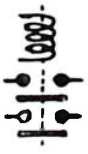
Negative Line-breaker interlock closed when negative line-breaker is *open*.

Trip Coil of Overload Relay energized by push-button switch in cab.

Re-set Coil of Overload Relay energized by push-button switch in cab.

Overload Relay contacts *closed* when overload relay is " set."

Overload Relay contacts *closed* when overload relay is " tripped."



No-volt Relay potential coil PR contacts *closed* when line voltage is available.

No-volt Relay low-current coil and contacts, the upper contacts *opened* and the lower contacts *closed* when current flows through main motors. LC

Series-parallel Switch Group interlock *closed* when group is at series-running position. PSG

Series-parallel Switch Group interlock *closed* when group is at parallel-running position. PSG

Series-parallel Switch Group intermediate interlock which *closes* after group moves from its series position and *opens* before switch reaches its parallel position. PSG

Field-shunting Contactor interlock *closed* when the contactor is open. FS1

Field-shunting Contactor interlock *closed* when the contactor is closed. FS1

Field-shunting Contactor magnet-valve coil energized when master controller is on notch 3 and series-parallel switch group has moved to its parallel-running position. FS1

Field-shunting Contactor magnet-valve coil energized when Field-shunting Relay contacts *close*. FS2

Field-shunting Contactor interlock *closed* when FS2 contactors open. FS2

Field-shunting Contactor interlock *closed* when FS2 contactors close. FS2

Field-shunting Relay contacts which *close* when the current through the relay coil subsides sufficiently, after FS1 contactors have closed. FSR

RPA Control Mechanism interlock *closed* when mechanism is at position 1. PC1

RPA Control Mechanism interlock *closed* when mechanism is at position 10. PC10

RPA Control Mechanism intermediate interlock which *closes* only *between* positions 1 to 10. PC INTER

TR — Testing Relay coil energized by O/L TRIP push-button switch in cab.

TR — Testing Relay interlock *closed* when TR coil is energized.

TR — Testing Relay interlock *opened* when TR coil is energized.

PC — No-volt Relay "potential" coil PR which is energized when 600 volt supply is available.

RPA — RPA Control Mechanism magnet-valve coil which admits air to move the mechanism up to position 10, the mechanism returning to position 1 when the magnet-valve coil is de-energized.

PSG — Series-parallel Switch Group magnet-valve coil, which admits air to move the group from series to parallel position, the group returning to series position when the magnet-valve coil is de-energized.

NR STOP — Notching Relay "stop" coil, energized only when master controller is on notch 1.

NR RATE — Notching Relay "rate" coil, energized only when master controller reverse handle is on FOR 1 position or on REV 1 position.

CON--DENSER — Condenser connected across the contacts of Notching Relay to reduce arcing when contacts open.

NR STOP — Notching Relay "stop" lever, which is operated when NR STOP coil is energized, and holds the Notching Relay contacts in *closed* position so that motors cannot accelerate beyond shunting speed.

TS — Testing Relay socket provided on each motor-car, to enable defective control equipment to be traced.

LB1 & LB2 — Line-breakers main contacts in main motor circuits.

1-2- ETC. — Cam-operated Contactors on RPA control mechanism.

PSG — Cam-operated Contactors on Series-parallel Switch Group.

PCM Control Equipment

Master Controller.

The master controller is of the British Thomson-Houston type C681A, and is shown in Fig. 2.

The controller is of the geared type with hinged dead-man's handle.

Its reverse drum has four positions:

(1) *Off.*—In which position the main contact drum is locked.

(2) *Forward* 1.—In which position the train accelerates at a reduced rate.

(3) *Forward* 2.—In which position the train accelerates at a high rate.

(4) *Reverse* 1.—For reverse direction of running.

The controller main drum provides for four conditions of running:

Notch 1. *Shunting.*—Motors connected in series with full field excitation and with all main resistance in use.

Notch 2. *Series.*—Motors in series with full excitation and main resistance cut out.

Notch 3. *Parallel.*—Motors connected in parallel with full field excitation and main resistance cut out.

Notch 3. *With Weak-Field Switch closed.*—Motors in parallel with reduced field excitation and main resistance cut out.

Contacts which make contact in the two forward and the "off" positions of the reverse drum are provided for the electro-pneumatic brake interlock circuit.

Contacts making only in the "off" position of the main drum are connected in the overload relay "set" circuit, to ensure that the main motor circuit is open before the overload relay can be "set."

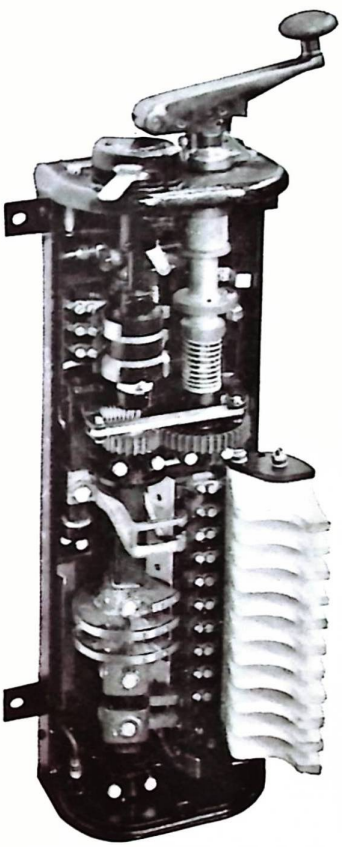


FIG. 2.—B.T.H. TYPE C681A MASTER CONTROLLER.

The controller is connected to the control train-line wires itemized in the table in Plate XXIX.

The wires from the control train-line pass through a multi-point control cut-out switch, fitted on each motor-car, so that a defective equipment can be cut out of action.

Automatic notching-up can be checked at any point by bringing the handle of the controller back to notch 1, but notching-back is not possible. To revert from parallel running to series running it is necessary to move the controller handle to " off " position, and then move to series position. As the acceleration system is of the automatic type, the master controller may be moved directly to the full parallel position, when the RPA control mechanism will notch up to full parallel position under the control of the notching relay.

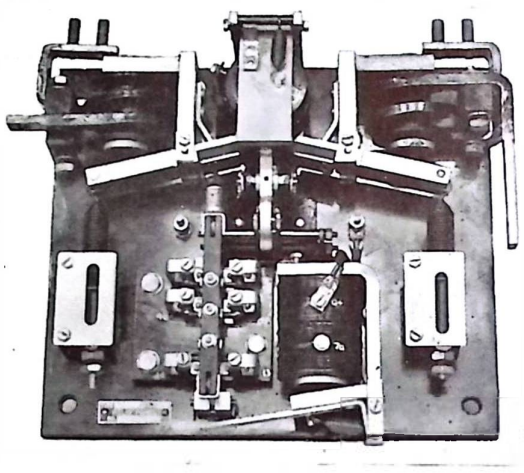


Fig. 3.—B.T.H. Type DBR209A Overload Relay.

With the weak-field switch closed, an intermediate weak-field notch is then taken, and then the final weak-field notch is taken under the control of the field-shunt relay. No weak-field notch is provided on the master controller, but a separate weak-field switch is provided which is incorporated in the marker-light unit. When the weak-field switch is closed, it energizes the field-shunting wire 8, and exhibits a yellow " flag " behind the window over the marker-light unit to announce that the train is being operated with its motors shunted.

Overload Relay.

The B.T.H. type DBR209A overload relay is shown in Fig. 3. The series-coils are fitted at the top of the panel, each coil operating a pivoted armature against the pull of a spiral spring which can be adjusted to suit the maximum permissible current through one of the main motors. Between the two main coils is fitted the shunt-trip coil for " tripping " the relay from the O/L TRIP switch fitted in the motorman's cab. The shunt re-set coil is shown lower down and serves to operate the O/L interlocks which control the line-breakers.

RPA102A Control Group.

The complete RPA control mechanism is shown in Fig. 4.

Fig. 5 shows diagrammatically the principle of operation of the mechanism. The mechanism consists of an air-engine operating a camshaft G through a rack and piston E and pinion wheel F.

When the magnet-valve coil M is energized, air is admitted to the oil reservoir Q, and the air from air-cylinder C is exhausted to

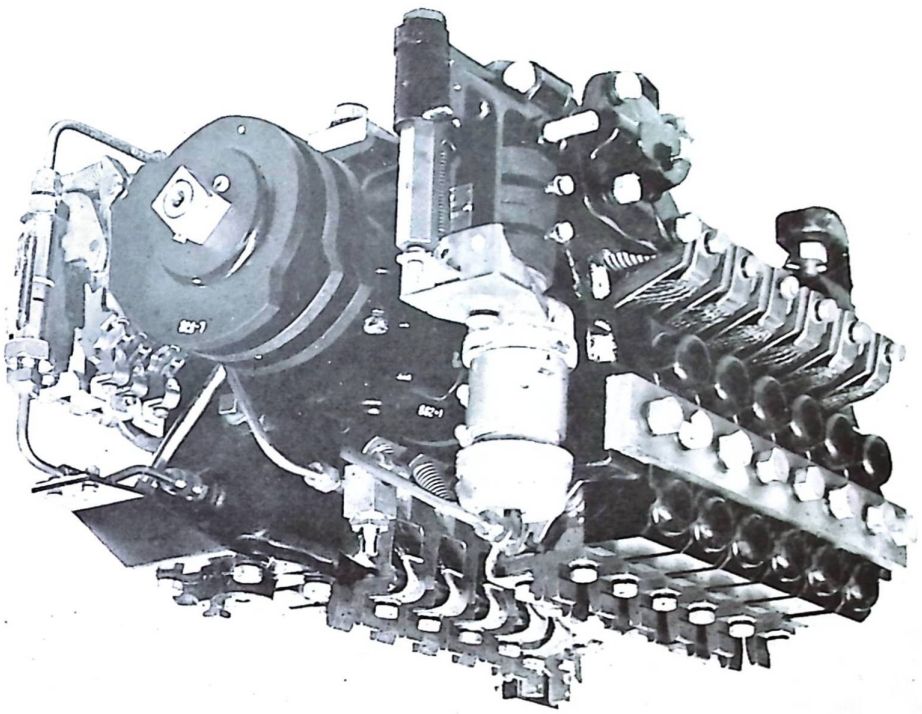


FIG. 4.—RPA CONTROL MECHANISM.

atmosphere. The piston E is thus moved towards the right, at a speed determined by the adjustable orifice T through which the oil must flow. This needle-valve orifice can be adjusted by means of a grub-screw, located behind a cover-nut at the end of the air-cylinder casting.

The time for the control mechanism to notch to full parallel position without main current should be three to four seconds.

The cam-operated contactors for the resistance notches are closed in sequence as the piston advances, but movement is held up when

the stop-coil K is energized, when a pawl is locked and prevented from moving out of the star-wheel notch.

The coil K is energized by the notching relay, and is de-energized under main current control, so that the RPA control mechanism advances step by step.

When the piston reaches the extreme end of its travel, all the accelerating resistances have been cut out of action, and also an

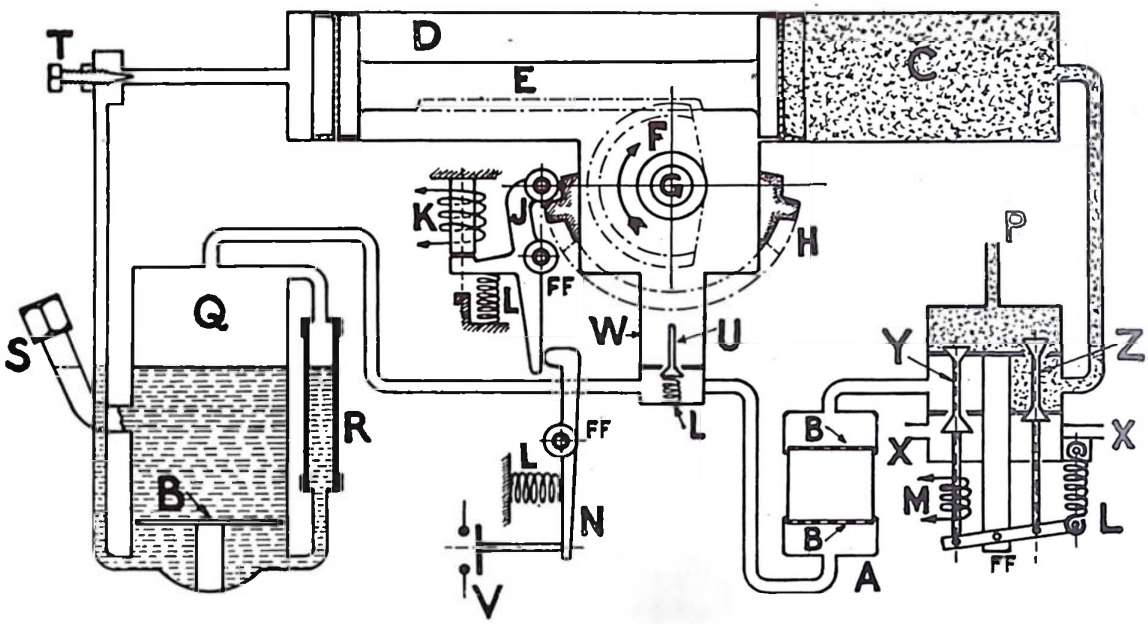


FIG. 5.—DIAGRAM OF RPA CONTROL MECHANISM.

A *Air Expansion Chamber.*
B *Baffles.*
C *Air Cylinder.*
D *Oil Cylinder.*
E *Double-end Piston.*
F *Pinion Wheel.*
G *Camshaft.*
H *Star-wheel.*
J *Star-wheel Stop Lever.*
K *RPA Stop Coil.*
L *Return Spring.*
M *Magnet-valve Coil.*
N *PC Inter Interlock Lever.*
P *Air-pressure Supply.*
Q *Oil Reservoir.*
R *Oil-level Gauge.*
S *Filling Pipe.*
T *Needle Valve.*
U *Sump Drain Valve.*
V *PC Inter Interlock.*
W *Oil Sump.*
X *Exhaust Ports.*
Y *On Valve.*
Z *Off Valve.*
FF *Fulcrum.*

interlock makes contact to permit the series-parallel switch PSG to operate.

If the master controller is on notch 3, the PSG switch changes the motor connections from series to parallel, and in doing so it introduces again the main resistances into circuit. As the PSG switch reaches its parallel position, the PSG interlock in the RPA magnet-valve circuit opens so that the RPA valve-magnet M is de-energized, and air pressure is admitted to the air end of the piston whilst it is exhausted from the oil reservoir.

The piston then returns to its original position under the control of the notching relay, again cutting out the main resistances, but of course in the reverse order.

The contactor units of the RPA control mechanism are opened by cams and closed by springs. Contactors 1 and 7 are closed in the "off" position, thus enabling the first step of control to be established without moving the RPA control mechanism. Contactors 1 and 7 are also closed on full-parallel position.

Any liquid that may leak past the piston E, flows down the pipe leading to the check-valve U. In the "off" and full-parallel positions of the mechanism there is no pressure on the bottom of the check-valve U, and the liquid flows down into the pipe leading to the oil reservoir Q.

At the next operation of the control mechanism, the air pressure in the pipe closes the check-valve U, and carries the oil along into the reservoir, thus preventing waste.

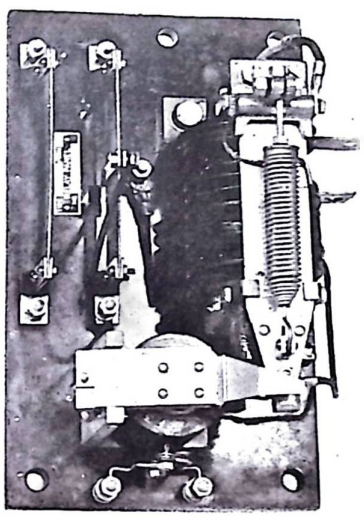


FIG. 6.—B.T.H. TYPE RMC1703A NOTCHING RELAY.

Notching Relay.

The B.T.H. type RMC1703A notching relay is shown in Fig. 6, and is provided with two series-coils, one in each main motor circuit, so that the "notching" current when the motors are connected in parallel is the *mean* of the two motor currents. A shunt "lift" coil energized by the closing of interlock PC INTER on the RPA control apparatus, or interlock PSG INTER on the series-parallel switch PSG, ensures that the relay is lifted between each notch. A shunt "rate" coil when energized enables the lower rate of acceleration to be obtained. The prolarities of the above-mentioned coils are such that their action is additive.

A "stop" coil is fitted, primarily to prevent the RPA control apparatus from operating when the master controller is on notch 1, and serves to check the progress of notching when desired.

The connections of the accelerating relay are shown in Plate XXIX.

Line-breakers.

One of the B.T.H. type MB24 line-breakers is shown partially dismantled in Fig. 7.

The line-breakers LB1 and LB2 are connected in the positive and negative motor leads respectively.

Each line-breaker consists of two contact elements connected in series, fitted with separate magnetic blow-outs and arc-chutes, each breaker being operated by a single air-engine.

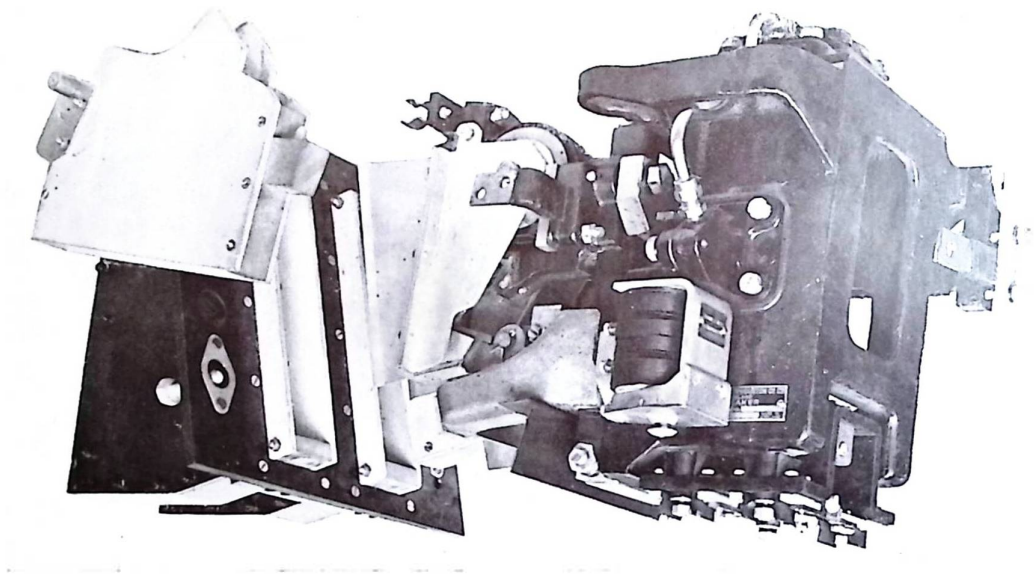


FIG. 7.—B.T.H. TYPE MB24 LINE-BREAKER.

Each line-breaker is controlled by a magnet-valve, the operating coil of which is energized (through various interlocks and control-line wires shown in the control diagram) by the master controller.

Reverser.

The B.T.H. type PB23A motor reverser is shown in Fig. 8, and is of the drum type operated by two separate air-engines, which throw it into either the " forward " or " reverse " positions.

The reverser is electrically interlocked with the line-breakers, to ensure that it is not moved from one position to the other unless the line-breakers are at their " open " position.

Series-parallel Switch Group (PSG).

The B.T.H. type PTS22A series-parallel switch is shown in Fig. 9, with one of the arc-chutes removed, and consists of an electro-pneumatic switch having three cam-operated contactors (P, S, and G) operated by a single horizontal air-engine.

Normally one of these contactors (S) is closed and the other two (P and G) are open. When the switch is operated by the air-engine, the transition of the motors from series to parallel is effected by the closing of its contactors P and G and the opening of contactor S.

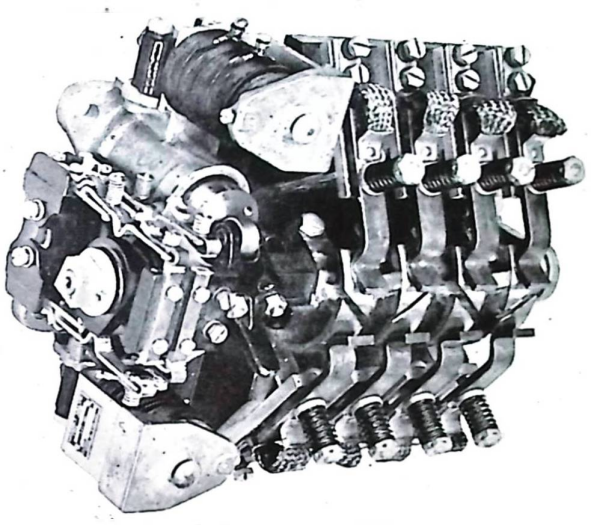


FIG. 8.—B.T.H. TYPE PB23A MOTOR REVERSER.

Field-shunting Contactors.

The field-shunting contactors FS1 and FS2 shown in Fig. 10 are B.T.H. type MB25A air-operated double-pole contactors with interlocks. The magnet-valves, which control the operation of these contactors, are shown in Fig. 11, and are separately mounted behind the notching relay.

When field-shunting is in operation, the motor field strength is reduced in two steps by the closing of FS1 contactor when full parallel is reached, and then by the closing of FS2 contactor under the control of the field-shunting relay.

Field-shunting Relay.

The relay used, B.T.H. type DBR71L, is shown in Fig. 26, page 449, Vol. II, and consists of a main coil which lifts a plunger, to which is attached a silver-faced interlock disc. An adjustable core is mounted on the plunger, and the position of this core determines the value of the current at which the plunger will drop and allow the interlock disc to make contact with the silver-tipped fixed

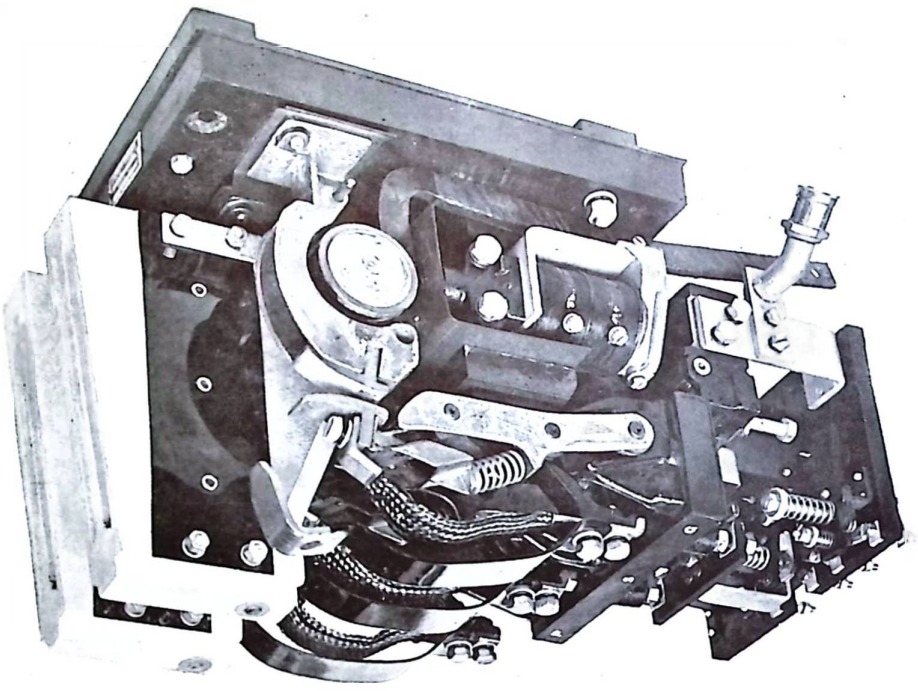


FIG. 9.—B.T.H. TYPE PTS22A SERIES-PARALLEL SWITCH GROUP.

contacts, so that current may flow to energize the magnet-valve coil of FS2 contactor and thus cause the contactor to close.

Field-shunting Resistances.

The resistances which are used to " shunt " the field magnet coils of the motors are made of wire grids, having a negligible temperature co-efficient. Tappings are provided, so that the motor field strength may be shunted to provide 75 per cent., 70 per cent., 65 per cent., or 60 per cent. of the full field.

No-volt Relay.

The no-volt relay consists of a series-coil element and a shunt-coil element used in conjunction.

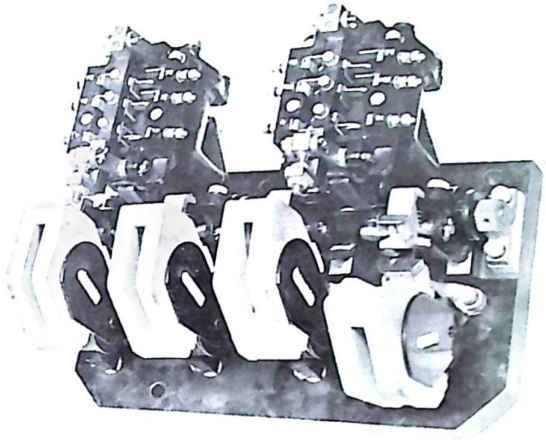


FIG. 10.—B.T.H. TYPE MB25A FIELD-SHUNTING CONTACTOR.

The shunt-coil element is shown in Fig. 12, being mounted on a panel with a similar element which is used as the testing relay.

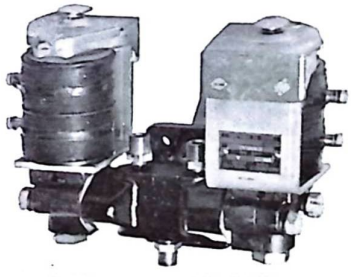


FIG. 11.—MAGNET-VALVES FOR FIELD-SHUNTING CONTACTORS.

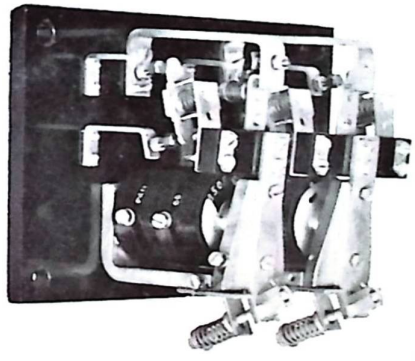


FIG. 12.—SHUNT ELEMENT OF NO-VOLT RELAY (AND TESTING RELAY).

The shunt-coil is energized so soon as the main supply voltage is applied, and permits of the line-breakers being closed.

The series-coil element is shown in Fig. 13.

The series-coil of the no-volt relay is energized so soon as current flows through the main motors, and its contacts break the circuit through the shunt-coil element, causing the contacts of that element to open.

Should the main motor circuit be interrupted, the series-coil is de-energized and the line-breakers are opened.

As the shunt-coil is energized by an "OUT" interlock on line-breaker LB2, it follows that the re-energization of the shunt-coil can only occur with the line-breakers open and with main supply voltage available.

In series with the shunt-coil are three 1500 ohm resistance units.

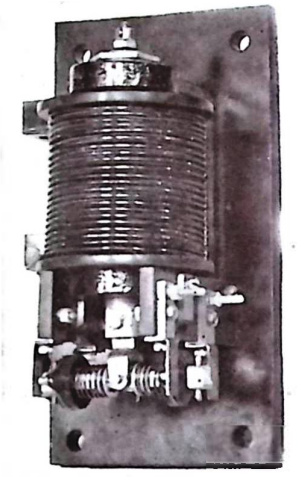


FIG. 13.—SERIES ELEMENT OF NO-VOLT RELAY.

Testing Relay.

As main isolating switches are not included in this equipment, a circuit is provided for testing the control group and the field-shunting contactors with the line-breakers open.

This testing circuit is fed through the contacts of the testing relay, the coil of which (TR) is connected in parallel with the O/L trip coil of the overload relay as shown on the control diagram. The testing relay is shown in Fig. 12 beside the shunt-coil element of the no-volt relay.

This arrangement ensures that the line-breakers are tripped whenever this circuit is used for test purposes.

It is necessary to hold the testing relay closed, by means of the O/L TRIP switch in the motorman's cab, when testing out the control and field-shunting contactors.

Control Equipment Assembly.

The control apparatus is carried under the motor-car floor, the whole of the items being mounted in a long flat case having removable protecting covers to facilitate work when the cars are standing over inspection pits.

The complete case is shown in Fig. 14 without its covers.

On the right-hand side the RPA control mechanism is seen with

its cables which lead to the main resistances. Next is fitted the series-parallel switch group PSG.

In the centre the two line-breakers are fitted.

In the left-hand space the reverser and the field-shunting contactors can be seen, while in the remaining space are fitted other parts of the equipment.

Indicating Device.

In order that the motorman or examiner can know that all of the motor equipments on a train are operating properly, a lamp is provided in the motorman's cab and is connected in series with interlocks on certain units of each equipment. When testing the control

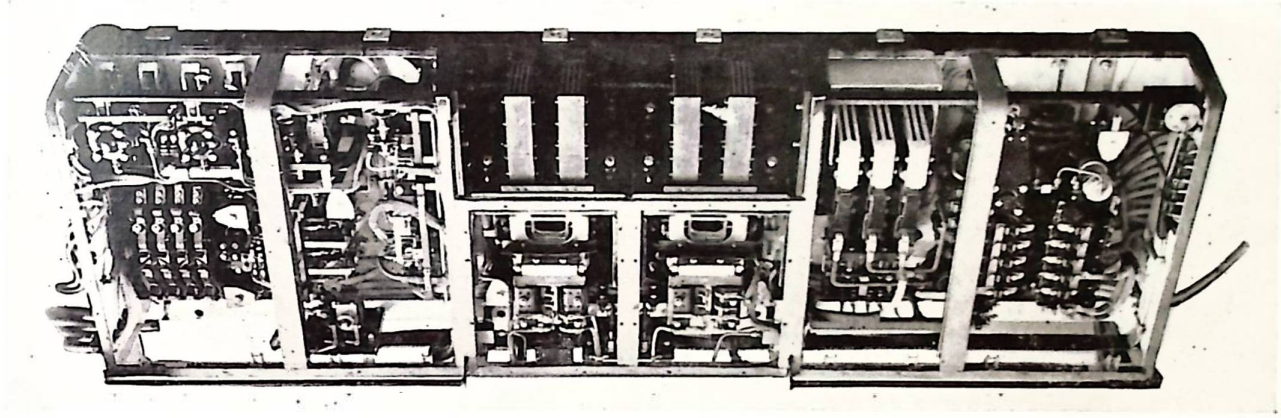


FIG. 14.—ASSEMBLED CONTROL APPARATUS.

equipments on the train in the depot without main current flowing through the motors, the indicating lamp will light up when all equipments have reached the weak-field running position.

In ordinary service the lamp will light up when all equipments reach the full-parallel position.

The indicating circuit is shown in Plate XXIX. A " test-socket " is fitted on each motor-car, so that by inserting a plug the PC1, PSG, etc., interlocks can be short-circuited, so that a defective equipment can be traced.

Equipment Control Governor.

A pressure switch is included in the equipment, to ensure that no piece of control apparatus shall attempt to operate at a lower pressure than that at which it can operate satisfactorily.

Main Circuit

In Plate XXIX the main and control circuits of a motor-car are shown in diagrammatic form. The movement of the contactors for each notch of the master controller is indicated on the sequence of contactors table, adjacent to the main circuit diagram.

When the controller handle is at " off " position, the RPA control mechanism stands at position 1, and the series-parallel switch PSG stands at series position. Contactors S, 1, and 7 are *closed*, and the line-breakers LB1 and LB2 are open.

When the controller is moved to the shunting notch 1, the line-breakers close so that current from the positive main fuse flows through line-breaker LB1, and one of the overload coils in the overload relay, through the armature and interpole coils of No. 2 motor, through the main contacts of the reverser, through the motor field-coils, through a main coil on the notching relay NR, through contactor 1 and the whole of RR main resistance, through contactor S and the whole of R main resistance, through contactor 7, through the armature and interpole coils of No. 1 motor, through the reverser main contacts and motor field-coils, through the coil of the field-shunting relay FSR, through the second main coil on the notching relay NR, through the series coil LC of the no-volt relay, after which the current passes through the second main coil of the overload relay and through line-breaker LB2 to the main negative fuse.

When the controller handle is moved to notch 2, the RPA control mechanism moves round from position 1 to position 10, under the control of the notching or accelerating relay, thus automatically cutting out the main resistance in nine " steps " and the two motors, being connected in series without resistance, run up to half-speed with full-field excitation.

As shown on step 10 of the contactor sequence table, the only contactors closed on full-series position are S, 5, 6, and 11.

When the controller handle is moved to notch 3, the transition from series to parallel working is effected by the action of the series-parallel switch PSG. As shown at transition step (T) of sequence table, contactors P and G close, the first to provide a connection from the positive main cable through R resistance for No. 1 motor, and the second to provide a connection from No. 2 motor through RR resistance to the negative main cable.

When these two contactors close, contactor S opens, leaving the

two motors connected across the positive and negative mains, each with an equal amount of resistance in circuit.

The RPA control mechanism then moves *back* from its position 10 to position 1 under control of the notching relay NR, cutting out the main resistances RR and R, so that the motors run up to full speed with full-field excitation. The only contactors closed on full-parallel step 19 are P, G, 1 and 7.

The motors are capable of accelerating to a higher speed when required. Provided the weak-field switch in the operating cab is closed, so that control-line wire 8 is energized when the master controller is on notch 3, the field-shunting contactors FS1 close after the RPA control mechanism reaches its full-parallel position (step 19), and by thus shunting some of the motor armature current past the motor field-coils, the magnetic flux through the armature is lessened and the motors speed up in an effort to produce the necessary back electro-motive force to balance the supply voltage.

As the motors accelerate, the current through them falls so that the current passing through the main coil of the field-shunting relay FSR is reduced to such a value that this relay operates to close field-shunting contactors FS2, which further reduces the motor flux and causes the motors to run up to their maximum free-running speed.

Control Circuit

Current for actuating the electro-pneumatic control apparatus is provided by a 50-volt motor-generator and storage battery.

The positive terminal of this low-voltage supply is "earthed," *i.e.* connected to the steel framework of the car, the negative connection to the master controller being made through a control key-switch and fuse, as shown in Plate XXIX.

On referring to this diagram, it will be seen that, with the control-switch closed, connection is established with contact finger *c* in the master controller through the control-fuse.

Overload Relay Circuit.

This relay is "set" or closed on all motor-cars when the O/L RESET switch in the operating cab is closed for a few moments.

When the switch is closed, control train-line wire 7 is energized (provided the master controller is at its "off" position, so that a segment connects fingers *f* and 7 together), so that current flows

through the O/L reset-coil, causing O/L1 and O/L2 contacts to close and O/L3 contacts to open.

These contacts are held in these positions by a mechanical catch.

The overload relay is "tripped" or opened when the O/L TRIP switch in the operating cab is closed, so that current flows through control train-line wire 6, through the O/L relay "trip" coil. When the O/L relay trips open, the O/L1 and O/L2 contacts are opened to interrupt the LB1 and LB2 magnet-valve circuits, and all line-breakers are opened instantly, and the contactors move to the positions shown in the "OFF" step in the sequence of contactors table.

The overload relay is also provided with main coils, connected in the main circuit of the line-breakers LB1 and LB2.

Should an excessive current flow through these main coils, the overload relay is automatically tripped open, with the same result as when the relay is tripped by closing the O/L TRIP switch in the operating cab.

Reverser Circuit.

Assuming that the reverse handle is moved to the position for forward running (FOR 1), and the controller handle is moved to notch 1, contact is established between a segment on the reverse drum and the contact finger connected with control train-line wire 0, and another connected segment on the reverse drum establishes contact with finger *a*; also, the two segments of the "dead-man's" drum establish connection between the negative finger *c* and finger *d*.

Control current from the positive pole of the 50-volt supply flows up through the interlock LB1 (which is fitted on positive line-breaker LB1 and is closed only if this line-breaker is open), through the reverser-throwing wire, through the magnet-valve coil FOR of the reverser, through the reverser interlock *l* to control train-line wire 4, and thence back through the contacts of the control governor (which are closed only if there is a full pressure in the brake train-pipe), through the reverse drum contacts and the dead-man's drum contacts to the negative pole of the 50-volt supply.

The reverser interlocks in the diagram are shown in the position they adopt when the reverser is set for *reverse* running. When the magnet-valve coil FOR is energized, the reverser is thrown over to its position for forward running.

When the reverser moves over into its forward running position, interlocks *l* and *m* open, while *k* and *n* close, so that the current

through FOR coil is interrupted, and interlock *n* is closed so that the reverser may be moved to reverse position when necessary.

Stop-coil Circuit.

As we have assumed that the handle of the controller has been moved to notch 1, finger *c* is connected to finger *d* by the dead-man's drum segments; and as finger *d* is connected by a wire to finger *e*, it follows that finger *e* is connected to finger 2 and a circuit is established from the control key-switch to control train-wire 2, and thence through the contacts 2 of the control cut-out switch on each motor-car to equipment wire 2.

Current is then able to flow from the positive pole of the 50-volt current supply, through the NR stop-coil of the notching relay, so that the RPA control mechanism is prevented from advancing beyond its position 1.

When the NR stop-coil is energized, it holds the contacts of the notching relay closed, so that current passes through the RPA stop-coil and holds RPA control mechanism stationary at position 1.

When the master controller is moved to notch 2 or 3, contact is broken between finger 2 and the controller combination-drum segment, so that the RPA control mechanism can then automatically advance by steps to half or full speed; but if the controller is moved back to notch 1, finger 2 is made alive again, and the NR stop-coil acts to check any further advance of the RPA mechanism.

Notch 1.—When the reverser moved over to its position for forward running (or if it was already in that position when the master controller was moved to notch 1), current from the positive pole of the 50-volt supply can flow through PC1 interlock (which is closed only when the RPA control mechanism is at position 1), through PSG interlock (which is fitted on the series-parallel switch PSG and is closed only when the PSG switch-group is in position for series running with contactor S closed), through FS1 interlock (which is closed only when the field-shunting contactors FS1 are open), through the magnet-valve coil of the positive line-breaker LB1, through the contacts of the equipment control governor (which are closed only if a proper air pressure is available to operate the air pistons of the control apparatus), through contacts O/L1 on the overload relay (which remains closed unless an excessive current flows through the main motors), through the interlock PR (which is fitted on the no-volt

relay and is closed only if the full ordinary voltage is available from the current rails).

(*N.B.*—When current actually flows through the main motors the interlock LC fitted on the no-volt relay closes, to provide an alternative path for the control current, and the interlock PR opens and remains open so long as main current continues to flow through the motor circuit.)

The control current then flows through reverser interlock *k*, as the reverser is now over to its forward running position, and current is able to pass to equipment wire 4 and thence through the control cut-out switch to control train-line wire 4, and through the reverse-drum and dead-man's drum of the master controller to the negative pole of the control current supply.

This current passing through the magnet-valve coil LB1 causes the positive line-breaker LB1 to close, and as it closes, the LB1 "IN" interlock mounted on this line-breaker closes and provides a by-pass connection to FS1, PSG, and PC1 interlocks, also an LB1 "OUT" interlock in the reverser throwing-wire opens to ensure that the reverser will not be moved while the line-breaker is closed.

As line-breaker LB1 closes, another LB1 "IN" interlock (shown just under the above-mentioned PC1 interlock) is closed, allowing current to flow through the magnet-valve coil LB2, through contacts O/L2 on the overload relay, through equipment wire 1 and thence to control-line wire 1 and finger 1 of the master controller.

As a combination-drum segment is in contact with finger 1 on all notches and thus connects finger 1 to finger *e*, the current can return to the negative pole of the control supply current via the control key-switch and fuse.

The energizing of the LB2 coil causes the negative line-breaker LB2 to close, so that, as contactor S is closed and contactors 1 and 7 are also closed, the motors are able to start and run slowly with all main resistance in circuit.

As line-breaker LB2 closes, an LB2 "IN" interlock is closed, in order that the magnet-valve coil RPA may be energized.

When the master controller is moved to notch 1, the segments on the dead-man's drum make contact with fingers *c* and *d*; in fact, this contact is maintained on all three notches. Only if and when the dead-man's handle is released by the motorman do these contacts separate, and thus break all connection with the control key-switch, causing all contactors and line-breakers to fall to "off" position. In addition, when this occurs, a small air valve is opened and opens

to atmosphere a larger valve connected to the brake train-pipe, so that the brakes are fully applied.

Notch 2.—When the master controller is moved to notch 2, the combination drum breaks contact with finger 2, so that the NR stop-coil circuit is interrupted.

The RPA magnet-valve coil became energized when the controller was on notch 1, the current from the positive pole of the control circuit passing through the coil, through FS2 "OUT" interlock (as the field-shunting contactors do not close until full-parallel working is reached), through PSG interlock (as the series-parallel switch is still in its position for series working), through LB2 "IN" interlock (as both line-breakers have closed), through equipment wire 1 to the negative pole of the control circuit.

When the NR stop-coil becomes de-energized, the notching relay is released and allows the RPA control mechanism to advance step by step from position 1 to position 10, its contactors closing in the order shown in the sequence of contactors table.

The connections for the notching relay are shown in the potential group circuit diagram on Plate XXIX.

Current for energizing the NR shunt-coil and the PC stop-coil is obtained from the 600-volt main-auxiliary fuse.

Across the notching relay contacts a "condenser" is connected to reduce arcing when the relay contacts are opened.

When the NR stop-coil is de-energized, the notching relay contacts open and the current flowing through the RPA stop-coil is interrupted, which results in the RPA mechanism moving from position 1 to position 2.

As the mechanism moves, from position 1, the interlock PC INTER closes so that current flows through the notching relay shunt-coil, through interlock PC INTER and through RPA stop-coil. The current through the shunt-coil of the relay causes the relay contacts to close, and the current through the RPA stop-coil locks the RPA control mechanism in position 2.

As the RPA mechanism approaches position 2, the interlock PC INTER opens and interrupts the flow of current through the relay shunt-coil, but the relay contacts are held closed by the heavy motor current flowing through the NR main coils, and therefore the RPA stop-coil remains energized.

As the speed of the main motors increases, the current passing through the NR main coils falls and, at a certain value, the relay

contacts open. This de-energizes the RPA stop-coil, which releases the RPA mechanism so that it moves round to position 3.

As the mechanism moves from position 2 to 3, the interlock PC INTER again closes so that the relay shunt-coil is again energized, and the relay contacts are closed to keep RPA stop-coil energized when the RPA mechanism reaches position 3 and the interlock PC INTER has opened to de-energize the relay shunt-coil. As the motor speed increases and the current through the NR main coils falls, the relay contacts again open to de-energize RPA stop-coil and permit of a further step forward of the RPA control mechanism.

This cycle of operations continues until position 10 is reached, when the motors run up to about half speed with full-field excitation, being connected in series with all main resistance cut out.

When the train is operated with the master controller reverse handle at forward position (FOR 1) or on reverse position (REV. 1), the notching relay "rate" coil is energized through train-line wire 0.

When this "rate" coil is energized it acts to assist the NR main coils, and therefore causes the notching relay contacts to open at a lower value of current through the NR main coils than would be the case with the NR main coils acting alone. Therefore the motors will accelerate at a lower rate when the NR "rate" coil is energized. When the controller reverse handle is on FOR 2 position, the "rate" coil is de-energized and the motors will accelerate at a higher rate.

When the reverse drum of the master controller is on FOR 1 position, current is able to pass from the positive pole of the 50-volt control circuit through the NR "rate" coil (which is fitted in the notching relay), through a calibrating resistance, through control train-line wire 0, to reverse drum finger 0, and thence through fingers *b*, *d*, and *c* to the negative pole of the control circuit.

Notch 3.—When the master controller is moved to notch 3, a segment of the combination drum makes contact with parallel finger 3 to energize control train-line wire 3, and if the weak-field switch is closed, also energizes finger 8 and control train-line wire 8. As the RPA control mechanism is already at position 10 and the interlock PC10 is closed, current from the 50-volt supply flows through the magnet-valve coil PSG of the series-parallel switch, through PC10 interlock, to control-line wire 3 and to the negative pole of the control supply.

The current through the PSG magnet-valve coil causes this switch group to move, closing contactors P and G and opening contactor S,

so that the motors are changed from series to parallel connection. As the PSG switch group moves from its " series " position, the PSG INTER interlock (shown to the right of the notching relay NR shunt-coil) closes, in order that current may flow through this coil to close the notching relay contacts, and through the RPA stop-coil to hold the RPA control mechanism at position 10.

When the series-parallel switch moves to its " parallel " position, it closes the PSG interlock shown to the left of PSG magnet-valve coil, so that a retaining connection is made to control-line wire 1 for use when interlock PC10 opens as the RPA control mechanism works back from position 10 to position 1 in parallel running. When the series-parallel switch reaches its " parallel " position, the PSG interlock shown to the left of RPA magnet-valve coil is opened, and by de-energizing RPA coil causes the RPA control mechanism to move backwards from position 10 under the control of the notching relay.

The PSG INTER interlock (to the right of the notching relay shunt-coil) opens as the PSG series-parallel switch reaches its parallel position, de-energizing the relay shunt-coil, but as the relay contacts have been closed, the RPA stop-coil remains energized.

As the current through the NR main coils subsides, the relay contacts open, causing RPA stop-coil to become de-energized and permitting the RPA control mechanism to move back to position 9. In doing so, its PC INTER interlock closes to energize the relay shunt-coil. When the PC INTER interlock opens, it de-energizes the relay shunt-coil, but the relay contacts remain closed to keep the RPA stop-coil energized.

As the motors gain in speed and the current through the NR main-coils subsides, the relay contacts again open to de-energize RPA stop-coil to permit the RPA control mechanism to move to step 8.

In this manner the notching relay operates to move the RPA mechanism step by step back to position 1, where all main resistance is cut out, and, as shown on the sequence of contactors table, only contactors P, G, 1 and 7 remain closed, the result being that the motors, being connected in parallel without resistance, are able to run up to their maximum speed with full-field excitation.

Field-shunting Contactors Circuit.

When the RPA control mechanism reaches its full-parallel position (and the weak-field switch is closed in the operating cab), current

flows from the positive pole of the 50-volt control circuit through PC1 interlock (which is closed because the RPA mechanism has moved back to its position 1), down through a PSG interlock (which is closed because the series-parallel switch is in its position for parallel running), through the FS1 magnet-valve coil, through control train-line wire 8, through the weak-field switch in the operating cab to the negative pole of the circuit.

The current passing through the FS1 magnet-valve coil causes the field-shunting contactors FS1 to close, to shunt some of the armature current past the motor field-coils to increase the motor speed above normal.

As these contactors close, the FS1 interlock (shown to the left of FS1 magnet-valve coil) closes to provide a " retaining " connection to control train-line wire 1, so that the field-shunting contactors remain closed until the master controller is moved to " off " position.

Another FS1 interlock shown to the left of the field-shunting relay FSR, closes to allow current to pass through FS2 magnet-valve coil, when the field-shunting relay contacts FSR close. These relay contacts close when the motors have increased in speed and the current through the relay main coil has subsided.

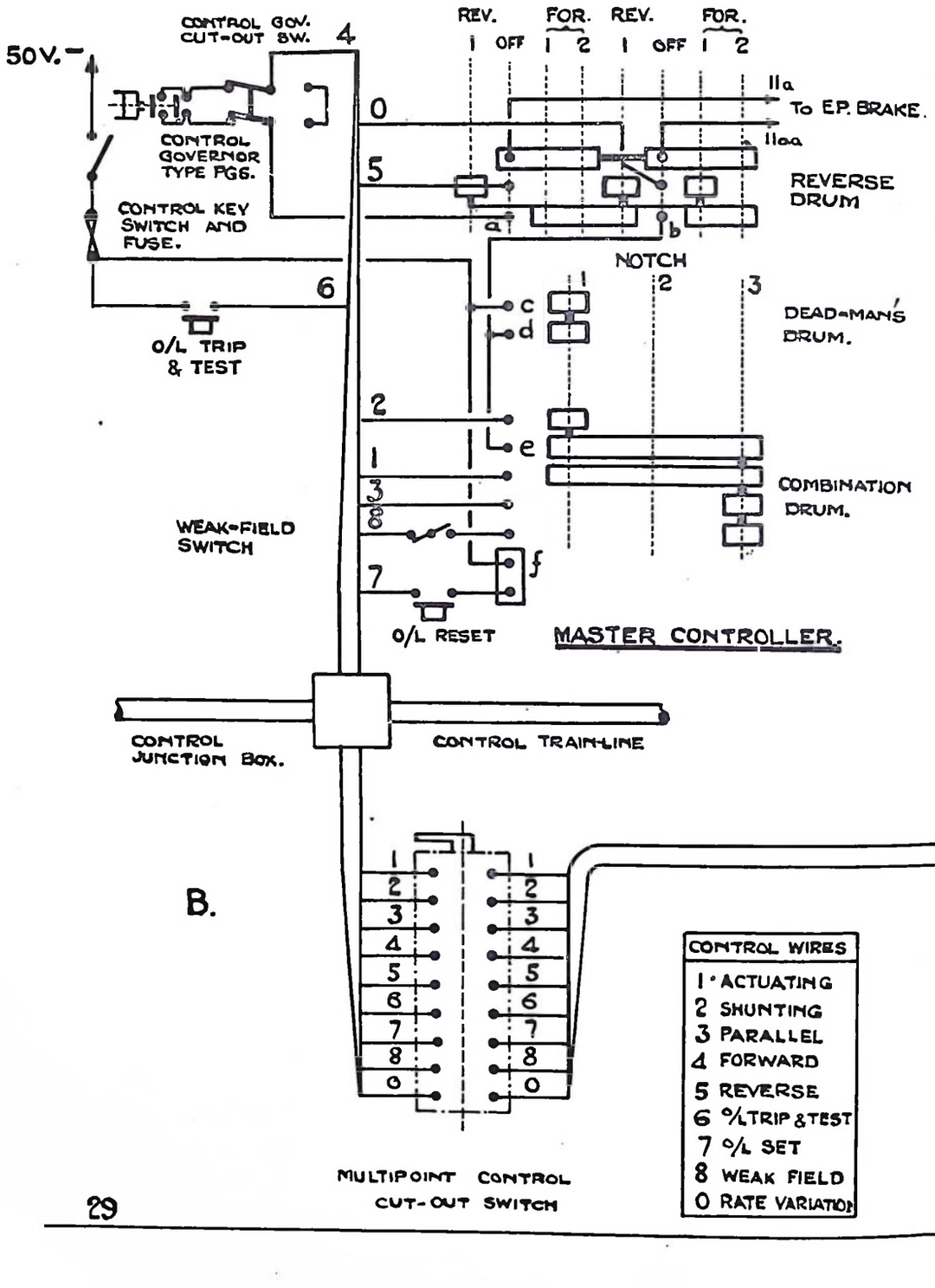
When the FS2 coil becomes energized, FS2 contactors are closed, and more current is shunted past the motor field-coils, causing the motors to run up to their maximum free-running speed.

As FS2 contactors close, the FS2 interlock shown under the field-shunting relay closes to maintain a circuit through FS2 magnet-valve coil, as the field-shunting relay contacts FSR will open owing to the increase in current through the relay main coil, due to the reduction in the motor field strength when FS2 contactors close.

No-volt Relay Circuit.

Current from the 600-volt main-auxiliary fuse passes through a PG fuse, through three 1500-ohm resistance units, through an interlock on no-volt relay (which is closed when no current is flowing through the LC coil), through an interlock on line-breaker LB2 (which is closed when line-breaker is open), through the " potential " coil PR of the no-volt relay, through a PG fuse to the negative main-auxiliary fuse.

Current passing through potential coil closes a contact shown under the coil, so that current may continue to pass through PR coil when line-breaker LB2 closes to start the motors and the LB2



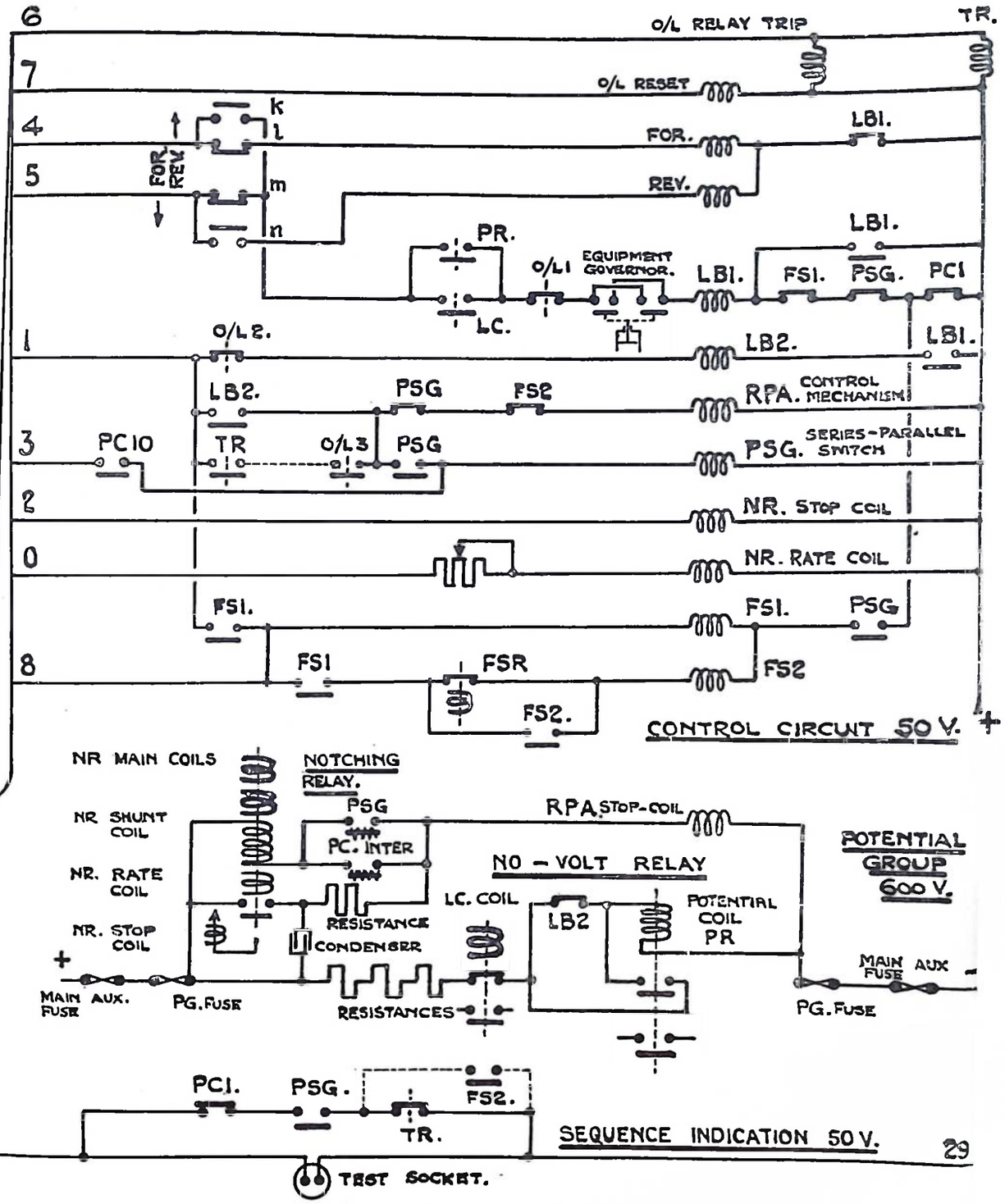
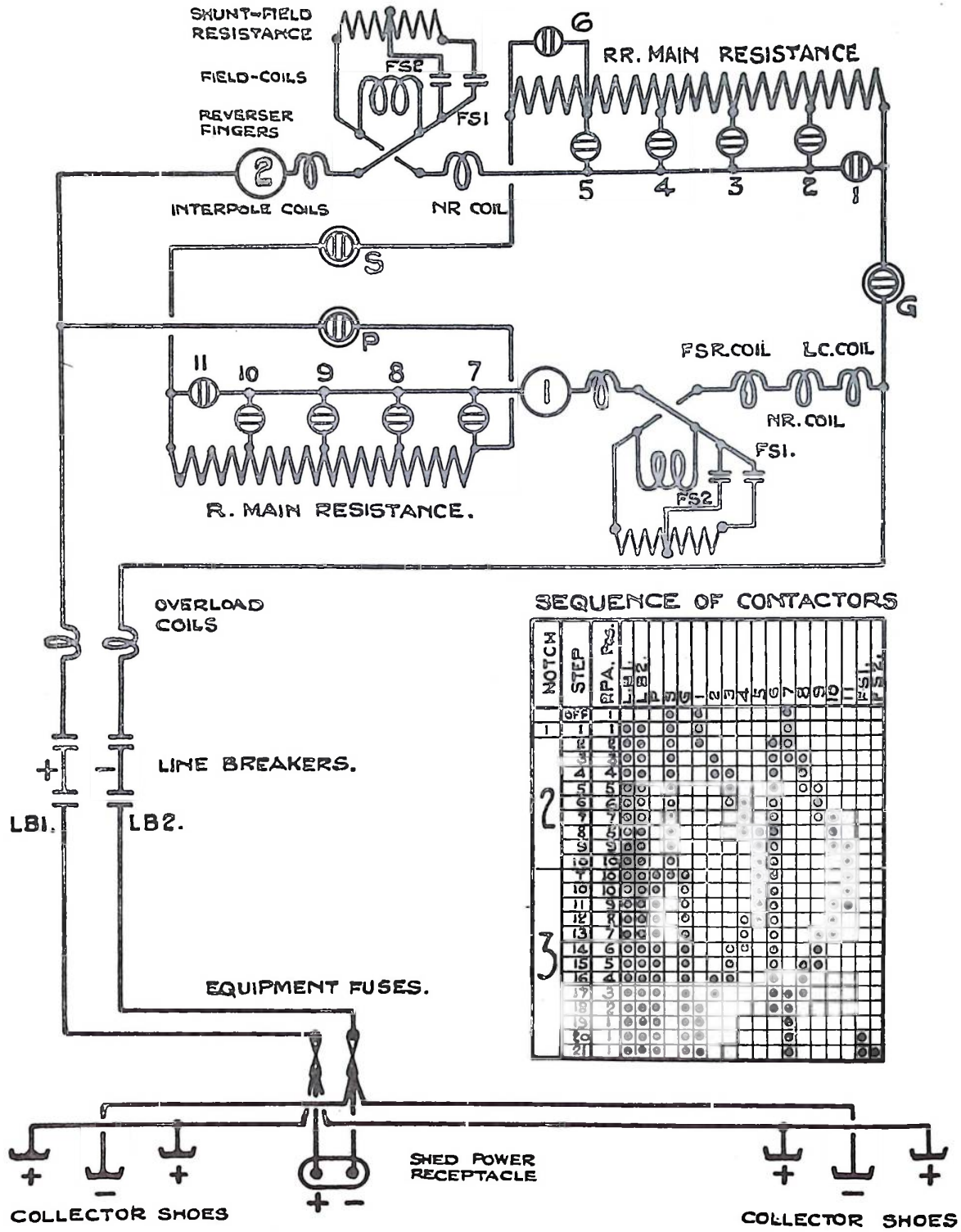


PLATE XXIX.—MAIN AND CONTROL CIRCUITS. LONDON TRANSPORT 1938 "TUBE" STOCK (B.T.H. EQ



T.H. EQUIPMENT)